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AIRSCREW-ENGINE COMBINATIONS and their EFFECT on the TAKE-OFF

Comparison of the Effect on Slow and Fast Aircraft of Various Means of Improving the Take-off Thrust

By G. V. LACHMANN, Dr.-Ing., A.F.R.Ae.S.

(*Continued from page 9, August 29, 1935 Issue*)

IN the following I propose to investigate the influence on two types of aircraft of the various means mentioned, *i.e.*, overboosting, two-speed gear, both combined, variable pitch airscrew, and variable pitch airscrew combined with overboost. The aircraft in question represent (i) the conventional service type of the past—still in use at present and for some time to come, and (ii) a type of the future. Both types are twin-engined machines and in the following will be termed "slow aircraft" and "fast aircraft" respectively. The aerodynamic characteristics of both types are considered to be sufficiently representative, so that a comparison on these lines will form a practical basis within fairly wide limits for generalised conclusions.

I. *Slow Aircraft.* Main aerodynamic characteristics:

Basic wing loading	12 lb./sq. ft.
Basic Power loading ..	12.5 lb./h.p.
Basic stalling speed	62 m.p.h.
Basic span loading	$W/4s^2 = 2.4$ lb./sq. ft. (on effective aerodynamic span.)
Parasitic drag area per h.p...	.02 sq. ft./h.p.

II. *Fast Aircraft.*

Basic wing loading	20 lb./sq. ft.
Basic stalling speed	63 m.p.h.
Basic span loading	2.9 lb./sq. ft.
Parasitic drag area per h.p...	.0073 sq. ft./h.p.
Basic Power loading ..	10 lb./h.p.

Thrust Curves

The following table contains the main characteristics of the airscrew/engine combinations investigated and the design limitations imposed upon the airscrew design. The general criterion for the choice of diameter is maximum efficiency at top speed and maximum r.p.m.

TABLE I.

Slow Aircraft.

Airscrew/Engine Combination.	Pitch Diameter Ratio.	Diameter.	Gear Ratio.	Design Limitations for Airscrew.
(a) Fully Supercharged Engine—4-Blader.				
Fixed Pitch Airscrew, rated maximum boost.	.9	12.48ft.	.5 : 1	Normal r.p.m. when climbing at rated altitude.
Fixed Pitch Airscrew, normal rated boost 2-speed gear.	.9	12.48ft.	.433 : 1	Normal r.p.m. for climb at Sea Level.
Fixed Pitch Airscrew, over-boost 8 lb./in.².	.9	12.48ft.	.5 : 1	—
V.P. Airscrew	.7	12.48ft.	.5 : 1	Normal r.p.m. for climb at Sea Level.
V.P. Airscrew	.55	12.48ft.	.5 : 1	Maximum r.p.m. during climb at Sea Level.
(b) Moderately Supercharged Engine—4-Blader.				
F.P. Airscrew, rated boost	.9	12.10ft.	.5 : 1	Normal r.p.m. during climb at rated altitude.
V.P. Airscrew	.7	12.10ft.	.5 : 1	Maximum r.p.m. at maximum rated boost.

Two-speed gear was not investigated, since considerable over-revving would occur.

Fast Aircraft.

(a) Fully Supercharged Engine—4 Blader.				
Fixed Pitch Airscrew rated maximum boost.	1.3	11.96ft.	.5 : 1	Maximum speed at 14,500ft., normal r.p.m. on climb.
Fixed Pitch Airscrew, over-boost 8 lb./in.².	1.3	11.96ft.	.5 : 1	Same airscrew as above.
Fixed Pitch Airscrew, 2-speed gear, overboost	1.3	11.96ft.	.433 : 1	Normal r.p.m. on climb at Sea Level.
Fixed Pitch Airscrew, 2-speed gear, maximum rated boost.	1.3	11.96ft.	.433 : 1	Normal r.p.m. on climb at Sea Level.
V.P.1 Airscrew, maximum rated boost.	.9	11.96ft.	.5 : 1	Normal r.p.m. on climb at Sea Level.
V.P.2 Airscrew, maximum rated boost.	.7	11.96ft.	.5 : 1	Maximum r.p.m. on climb at Sea Level.
V.P. Airscrew, overboost	.9	11.96ft.	.5 : 1	Normal r.p.m. just attained on take off.

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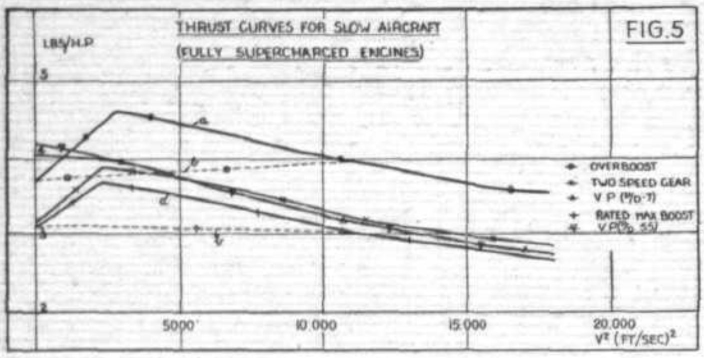


FIG.5

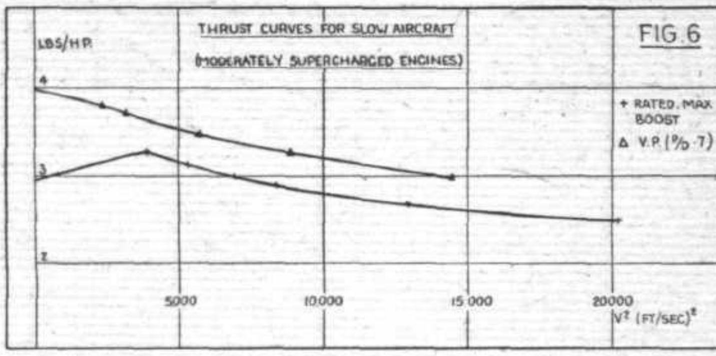


FIG.6

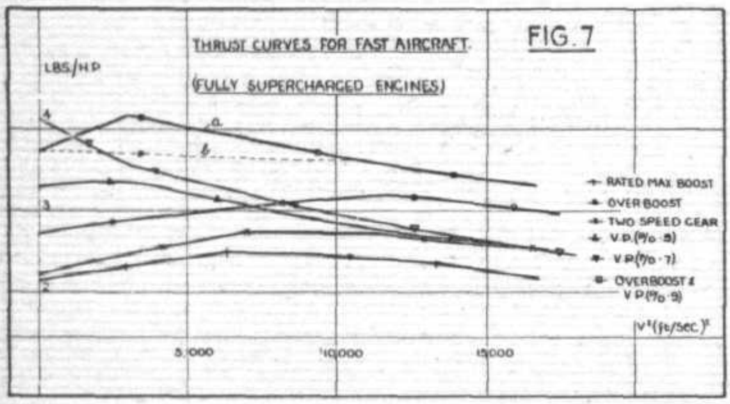


FIG. 7

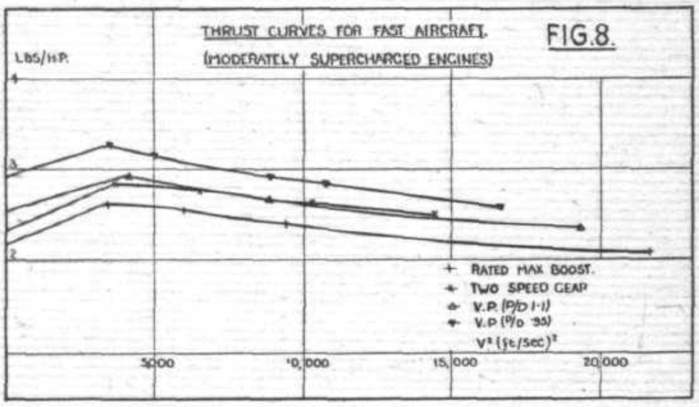


FIG.8.

Airscrew/Engine Combination.	Pitch Diameter Ratio.	Airscrew Diameter.	Gear Ratio.	Design Limitations for Airscrew or Gear.
*(b) Medium Supercharged Engine—3-Blader.**				
Fixed Pitch Airscrew, rated maximum boost.	1.25	11.96ft.	.5 : 1	2,300 r.p.m. at maximum speed at 4,750ft.
Fixed Pitch Airscrew, 2 speed gear, rated maximum boost.	1.25	11.96ft.	.463 : 1	Normal r.p.m. on climb at 4,750ft.
V.P Airscrew rated maximum boost.	.95	11.96ft.	.5 : 1	Maximum r.p.m. on climb at Sea Level.
V P Airscrew, rated maximum boost.	1.1	11.96ft.	.5 : 1	Normal r.p.m. on climb at Sea Level.

The results obtained for slow and fast aircraft fitted with various airscrew-engine combinations are given in Diagrams 5–8, where the ratio of net thrust/maximum permissible take-off h.p. at maximum rated boost is plotted as a function of V^2(ft./sec.)^2 in view of a great simplification obtained in the calculation of the unstick run as is shown in the Appendix. The net or propulsive thrust is expressed as:

$$T = Q/D.K_T/K_Q.\eta_{pr}$$

where the term $\eta_{pr} = 1 - \dfrac{Af\ J^2}{D^2\ K_T}(S - 1)$

$$S = \left(\frac{\text{Velocity in slipstream}}{\text{Free air velocity}}\right)^2$$

$$J = V/nD$$

Af = Parasite drag area in slipstream

accounts for the increase of drag due to slipstream. (For derivation of this, see "The Propulsive Efficiency of an Airscrew," by R. S. Stafford, *The Aircraft Engineer*, March 30, 1933.)

For the overboosted engine combined with variable pitch or fixed pitch airscrews, the calculations of take-off run were carried out both for curve A (optimistic) and B (pessimistic).

The table gives a comparison between the actual static thrust which was used in the calculation based on American full scale tests compared with the static thrust calculated from wind tunnel results.

* A three-blader had to be chosen in order to retain the same diameter of 11.96ft. as in the case of the supercharged engine.

TABLE II.

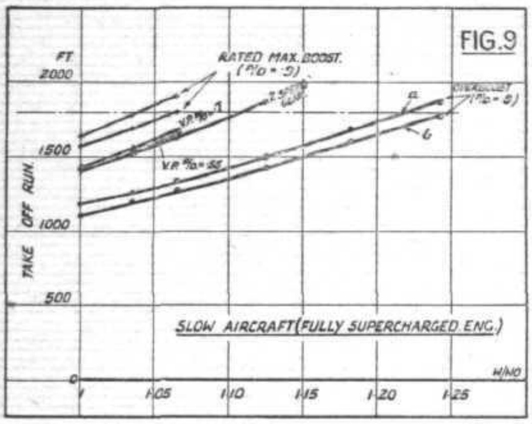
Airscrew Combination.	P/D.	B.H.P.	Static R.P.M.	Static Thrust based on American Full Scale Tests.	Static Thrust Calculated on basis of R. & M. 829.	Ratio.
Fast Aircraft—Fully Supercharged.						
Fixed Pitch ...	1.3	547	1,560	2.950	3,430	.860
Overboost ...	1.3	817	1,795	3,710	4,270	.869
2 Speed	1.3	663	2,075	3,040	3,750	.812
V.P. (.9)	.9	648	1,970	4,220	4,410	.957
V.P. (.7)	.7	683	2,245	5,490	5,150	1.086
Overboost and V.P. (.9) ...	.9	890	2,190	5,090	5,760	.884
Slow Aircraft—Fully Supercharged.						
Fixed Pitch ...	.9	625	1,820	4,290	5,060	.850
Overboost ...	.9	860	2,010	5,120	6,350	.808
2-Speed	.9	670	2,135	4,350	5,340	.814
V.P. (.7)	.7	662	2,065	5,475	5,720	.960
V.P. (.55) ...	.55	692	2,320	6,440	5,720	1.13
Fast Aircraft—Moderately Supercharged.						
Fixed Pitch ...	1.25	672	1,950	3,310	3,850	.860
2-Speed	1.25	762	2,200	3,560	4,180	.852
V.P. (1.1) ...	1.1	744	2,150	3,870	4,860	.797
V.P. (.95) ...	.95	800	2,380	4,470	5,680	.788
Slow Aircraft—Moderately Supercharged.						
Fixed Pitch ...	.9	708	2,050	4,500	6,080	.740
V.P.	.7	795	2,350	6,050	6,500	.931

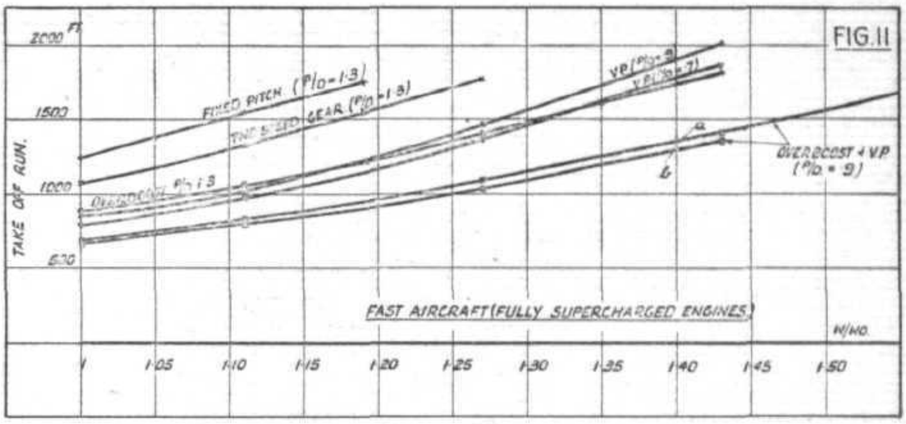
Influence on Take-off Run

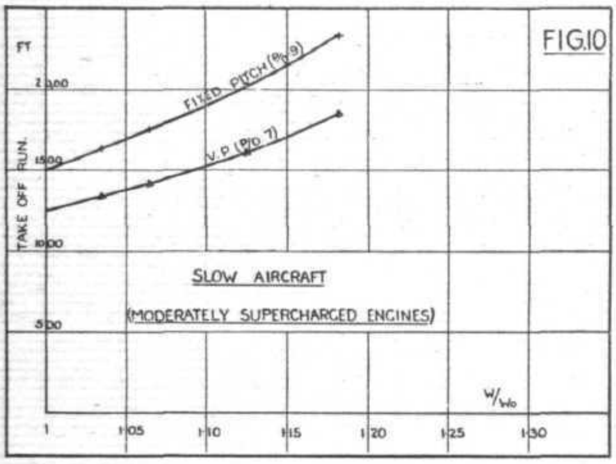
Although the curves for the net thrust already give a fairly good indication of the efficiency of the various airscrew/engine combinations, it is thought that the influence on the complete take-off run forms the decisive criterion. The take-off run (s) consists of three phases: the unstick run (s_1), the horizontal distance travelled during the change of flight path angle (s_2), and the climb over the 60ft. obstacle (s_3). The distances taken for the three different phases have been calculated according to a semi-graphical method set out in the Appendix.

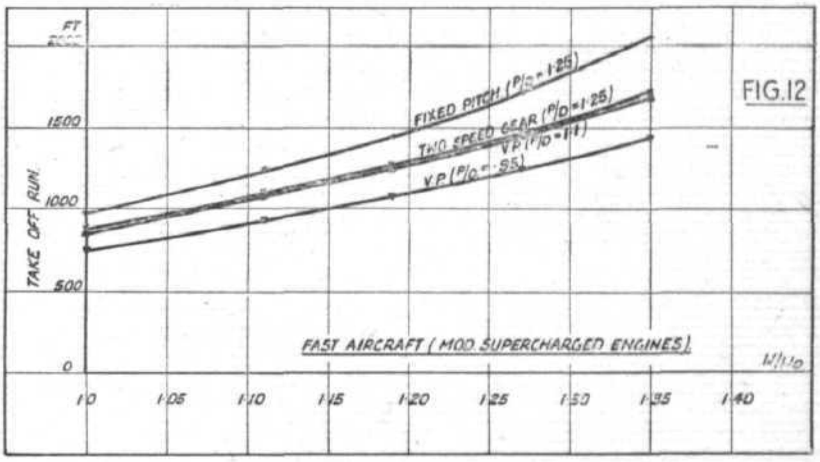
The following general assumptions have been made:

1. The slow aircraft accelerates at an angle corresponding to $K_D - \mu K_L$ = Min. The fast aircraft fitted with flaps which in practice cannot satisfy this optimum condition accelerates with horizontal thrust line.
2. Ground friction coefficient $\mu = .05$









3. Unstick speed = initial climbing speed = 1.2 × stalling speed.
4. The slow aircraft has an ordinary wing K_L max = .575, while the fast aircraft is fitted with slotted flaps set at 40 deg., giving a K_L max = 0.92.
5. The change of flight path angle from unstick run into climbing path is along a circular arc. The necessary centripetal acceleration is obtained by an excess of lift over weight, *i.e.*, after unsticking at 1.2 V_s, the pilot increases the angle of the aircraft, the forward speed remaining constant.

The results are plotted in Diagrams 9 and 10 for the slow aircraft with fully and medium supercharged engines, and in Diagrams 11 and 12 for the fast aircraft with fully and medium supercharged engines.

In these diagrams the total run is plotted as a function of W/Wo, where Wo = basic weight. On this basis the curves indicate to what extent the basic aircraft could be overloaded within the limits of the take-off requirements. On the other hand, these curves also give an indication of the total take-off run obtained with an aircraft designed for different horsepower and wing loadings (increased over basic figures at the same ratio as W/Wo), with the aspect ratio of the wings and the parasitic drag/horsepower as constant parameters. In order to show the magnitude of the partial runs which compose the total take-off run (s), figures for s_1, s_2 and s_3 are given for the basic types of aircraft in Table II.

The runs are expressed in feet.

Type of Engine.	Airscrew/Engine Combination.	Slow Aircraft.				Fast Aircraft.			
		s_1	s_2	s_3	s	s_1	s_2	s_3	s
Moderately Super-charged.	Fixed Pitch ...	975	55	472	1,502	564	47	378	989
	Two Speed Gear	—	—	—	—	505	56	315	877
	Variable Pitch (P/D .7) ...	798	69	376	1,243	—	—	—	—
	Variable Pitch (P/D 1.1) ...	—	—	—	—	491	56	315	862
	Variable Pitch (P/D .95) ...	—	—	—	—	425	65	270	760
Fully Super-charged.	Fixed Pitch ...	990	50	520	1,560*	723	38	467	1,228
		1,080	50	520	1,630†	—	—	—	—
	Two Speed Gear	896	57	455	1,408	648	48	371	1,067
	Overboost ...	713	81	319	1,113*	522	59	298	879
		780	81	319	1,180†	—	—	—	—
	Variable Pitch (P/D .55) ...	873	52	481	1,403	—	—	—	—
	Variable Pitch (P/D .7) ...	895	52	481	1,428	—	—	—	—
	Variable Pitch (P/D .9) ...	—	—	—	—	475	54	329	858
	Variable Pitch (P/D .7) ...	—	—	—	—	429	58	305	792
	Overboost and V.P. (P/D .9)	—	—	—	—	371	80	220	671*
		—	—	—	—	390	80	220	690†

* and † refer to the "optimistic" and "pessimistic" thrust curves respectively.

Moderately Supercharged Engines. Both fixed pitch and variable pitch airscrews show an improvement in take off over equivalent arrangements in the case of fully supercharged engines. The combination of variable pitch airscrew and moderately supercharged engine is about as efficient as fixed pitch airscrew + overboost.

(a) Results Obtained for Slow Aircraft

Fully Supercharged Engines. Overboost combined with a fixed pitch airscrew is by far the most effective means to shorten the take-off run or to increase the capacity to take off with overload. The overload capacity is increased by 18 per cent. over the value obtainable with fixed pitch airscrew and rated maximum boost. The two-speed gear is as efficient as variable pitch airscrews, but neither device seems worth while on this type of aircraft from the take-off point of view.

(b) Fast Aircraft

Fully Supercharged Engines. As regards overloading, the most efficient method is a combination of overboosting and variable pitch airscrews. This permits increasing the limiting overload of the basic aircraft fitted with fixed pitch airscrews by about 34 per cent. However, it is also a very noteworthy result that overboosting combined with a fixed pitch airscrew is nearly as effective as using variable pitch airscrews together with engines of normal take-off

boost. It would follow from this result that where the take-off run is the decisive design consideration and where an excessive overloading case is not required, the use of overboost as a simpler and cheaper technical solution may eliminate variable pitch airscrews. However, this method will probably be limited to certain military aircraft only where cheapness, weight saving and operational simplicity count more than long life of the engine. Using a variable pitch airscrew will always be a sounder engineering policy. The two-speed gear is about half as effective as variable pitch airscrews. No substantial advantage for the take-off is gained by combining two-speed gear with overboosting. (The curve relating to this combination has been omitted in the diagram to avoid overcrowding.)

Moderately Supercharged Engine

The fixed pitch airscrew gives about 10 per cent. higher overload capacity in this case than with fully supercharged engine. The two-speed gear is about identical in effect with variable pitch airscrews giving normal r.p.m. Variable pitch airscrews giving maximum r.p.m. approach the take-off efficiency of variable pitch airscrews combined with overboosted engines.

Summed up, this means to say that under present conditions based on the use of 87 octane fuel the moderately supercharged engine by itself or the two-speed blower engine, respectively, combined with variable pitch airscrews giving maximum r.p.m. will give the best take-off and the greatest overload capacity.

The take-off of the basic aircraft even with fixed pitch airscrew is so good with either fully or moderately supercharged engines that the use of variable pitch airscrews would hardly be justified in this particular case.

The following figures give some idea of one combination of extreme limits within which the existing take-off requirements can be satisfied for the most efficient airscrew/engine combination.

Wing loading	about 30 lb./sq. ft.
Take-off h.p. loading ..	about 13 lb./h.p.
Span loading $W/4_s{}^2$	about 4 lb./ft.^{2}

or, expressed differently, an aircraft could be designed for a total all up weight of 40,000 lb., a span of 100ft., a wing area of 1,330 sq. ft., and total take-off horsepower of about 3,100.

The above investigation deals with take-off conditions only and it is, of course, admitted that even in such cases where the variable pitch airscrew is not an essential asset from the take-off point of view, the performance of the aircraft would certainly benefit in other respects, especially in regard to rate of climb and cruising at altitude.

Certain findings in this investigation which are at the moment purely analytical, for example, the influence of overboosting, will require experimental confirmation.

APPENDIX

Method Employed for Calculating the Take-off Run

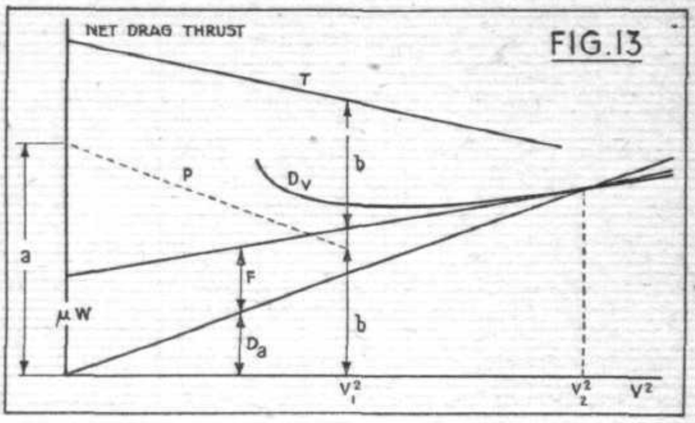
Unstick Run.

The usual method is based on a "V" basis which makes integration rather cumbersome. The integration becomes very much simpler and more rational if a "V^2" or "$\frac{1}{2}\rho V^2$" basis is chosen†; in addition, the calculations can be greatly simplified as the thrust, or effective propulsive force respectively, can be fairly well approximated in most cases by a linear law. Drag and ground friction are already linear functions of V^2. In Diagram 13 the following symbols are used.

* M. Schrenk, "Abflug und Schraubenschub," D.V.L. Rep. Nr. 305; Z.F.M. 1932, Nr. 21.

† G. Lachmann: "Flaps and the Take-off," Journal of the Aeronautical Sciences, Vol. 2, No. 5, May, 1935.

FIG. 13



T	=	Net Thrust = $T_0 . \eta_{pr}$
η_{pr}	=	propulsive efficiency
v_1	=	unstick speed (assumed throughout the above calculations = 1.2 stalling speed).
v_2	=	airborne veloc. corresponding to attitude of unstick.
F	=	μW = ground friction.
D_a	=	Air drag during unstick.
D_v	=	airborne drag.
P	=	net accelerating force = T − (D_a + F).
a	=	value of P at $v = o$
b	=	value of P at v_1.

From energy considerations follows:

$$P\,dl = \frac{W}{2g}\,d\,(v^2)$$

or $$dl = \frac{W}{2g}\frac{d(v^2)}{P}$$

now $$P = a - \frac{a-b}{v_1{}^2}\,v^2$$

hence

$$s_1 = \frac{W}{2g}\int_0^{v^2}\frac{d(v^2)}{a - \dfrac{a-b}{v_1{}^2}\,v^2} = 2.30\frac{W}{2g}\,\frac{v_1{}^2}{a-b}\log_{10}\left(\frac{a}{b}\right)$$

= length of unstick run.

At the end of the unstick run the pilot increases the angle of incidence and in order to obtain an upward inclination of the flight path at an angle θ the aircraft has to fly through an arc $R\theta$. The projection of this arc on the horizontal represents an additional loss of distance s_2. The centripetal force is obtained by the increase of K_L. It can be shown that:

$$s_2 = \frac{b}{2W\,.\,g}\cdot\frac{v_1{}^2}{K_L\text{max}/K_{L1} - 1}$$

This loss of distance is usually neglected in take-off calculations, which in view of the order of magnitude of this distance is really not permissible. The use of flaps materially shortens this distance. In the foregoing the following values have been generally used.

For slow aircraft:

$$K_{L1} = 0.4$$
$$K_L\text{max} = 0.575$$

For fast aircraft (assumed to be fitted with slotted flaps):

$$K_{L1} = 0.64$$
$$K_L\text{max} = 0.92$$

20 per cent. increase due to slipstream has been taken into account.

Climb.

$$s_3 = \frac{h}{tg\,\theta} = \frac{W \cdot h}{b}$$

h = height of obstacle = 60′.

Total take-off run $s = s_1 + s_2 + s_3$.

A more detailed description of this method is given in the article entitled "Flaps and the Take Off," published in the Journal of the Aeronautical Sciences.

Effect of Weight Increase

The effect of weight increase is easily dealt with. The air drag during the unstick run is not effected as the aircraft is not yet airborne and is accelerated at the same attitude, *i.e.*, at the same $K_L \cdot v_1^2$, *i.e.*, the square of the take-off speed, changes of course in proportion to the increase of wing loading. Change of parasitic drag due to the slightly higher incidence can safely be neglected in the case of aerodynamically clean aircraft and one is left with a correction for induced drag:

$$D_i = \frac{2}{\pi \rho v_1^2}(W_2^2 - W_1^2).$$

With the help of the generalised thrust curves, which, of course, are strictly correct only for the Bristol family of air-cooled engines, and using the above given simple formula, the most suitable airscrew/engine combination can be determined in each particular case. It should be noted that the assumed propulsive efficiency is based on the now standardised wing/nacelle arrangement, and in the case of military aircraft requires no correction. For a single-engined aircraft the propulsive efficiency may require some adjustment.

NOTE ON THE FORM FACTOR OF SPRUCE BEAMS

Taking into Account Ratio of Web Thickness to Total Width of Beam

By R. RODGER

IN two recent issues of *The Aircraft Engineer* articles have appeared dealing with refinements in the design of spruce beams, one of the points discussed being the effect on the limiting stresses of the geometry of the beam cross-section, *i.e.*, the form factor. Several years ago I was privileged to acquire, by the kindness of an American friend, certain data of a similar nature developed by the Forest Products Laboratory, Forest Service, United States Department of Agriculture. In view of the recent revival in these pages of the question of spruce spar design I feel that this data might be of immediate interest to readers.

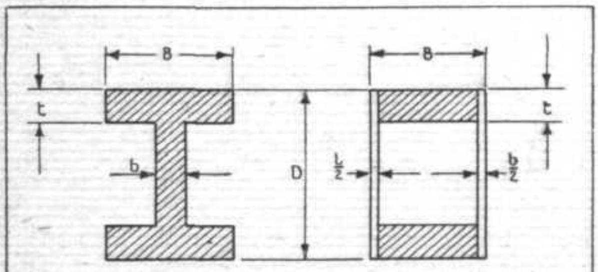


FIG. I

The American tests on I-section and box spars have indicated that a decrease in the web thickness results in a serious reduction in the modulus of rupture, in addition to which thin webs result in increased deflections and secondary stresses. Tables I and II give the original American data referred to the lettering of Fig. 1, both quantities—the modulus of rupture and the elastic limit in bending—being dependent on the ratio of compression flange thickness to total depth of beam and the ratio of web thickness to total width of beam. It is interesting to note that neither Prager nor Cuss appear to take into account the effects of the latter ratio.

TABLE I.

MODULUS OF RUPTURE. lb./sq. in.

b/B	Ratio t/D.									
	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50
.1	5,380	5,600	5,850	6,180	6,480	6,820	7,190	7,550	7,900	8,300
.2	5,830	6,050	6,270	6,550	6,830	7,150	7,430	7,760	8 100	8,430
.3	6,280	6,450	6,660	6,890	7,120	7,390	7,680	7 950	8,750	8,540
.4	6,720	6,890	7,050	7,260	7,470	7,700	7,930	8,180	8,410	8,640
.5	7,180	7,300	7,450	7,610	7,790	7,980	8,180	8,380	8,580	8,760
.6	7,630	7,730	7,850	7,990	8,130	8,280	8,430	8,600	8,750	8,900
.7	8,080	8,160	8,250	8,340	8,440	8,580	8,690	8,800	8,910	9,020
.8	8,500	8,580	8,630	8,700	8,760	8,850	8,910	8,980	9,080	9,160
.9	8,990	9,000	9,040	9,080	9,100	9,120	9.160	9,200	9,250	9 300
							Solid Rectangle ...			9,400

TABLE II.

ELASTIC LIMIT IN BENDING. lb./sq. in.

b/B	Ratio t/D.									
	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50
.1	4,320	4,430	4,560	4,710	4,850	5,020	5,180	5,380	5,520	5,710
.2	4,520	4,620	4,750	4,860	5,000	5,120	5,280	5,460	5,590	5,740
.3	4,740	4,820	4,920	5,030	5,150	5,260	5,390	5,520	5,670	5,800
.4	4,960	5,030	5,110	5,220	5,300	5,410	5,500	5,620	5.750	5,850
.5	5,150	5,240	5,310	5,400	5,470	5,540	5,620	5,720	5,810	5,910
.6	5,390	5,410	5,480	5,520	5,600	5,680	5,740	5,810	5,900	5,960
.7	5,590	5,610	5,650	5,700	5,750	5,810	5,860	5,910	5,980	6,020
.8	5,760	5,800	5,810	5,850	5,900	5,930	5,980	6,000	6,040	6,100
.9	5,990	5,990	6,000	6,000	6,020	6,040	6,080	6,100	6,120	6,150
							Solid Rectangle ...			6,200

NEW BRITISH STANDARDS NUMBERS

The following specifications have just been published by the British Standards Institution: 3 L.25. Aluminium Alloy Bars and Forgings ("Y" Alloy) L.43. Aluminium Alloy Drop-forgings for Pistons and Cylinder Heads ("Y" Alloy). Specification 3 L.25, which is a revision of B.S. Specification 2 L.25, covers the alloy generally known as "Y" Alloy, and deals with bars and billets for forging, bars for machining (not exceeding 3 inches thick), and forgings (including pistons other than drop-forgings). This specification also replaces the Air Ministry Specification D.T.D. 191 for "Y" Aluminium Alloy Forgings and Stampings.

B.S. Specification L.43 is a new Specification covering "Y" Aluminium Alloy Drop-forgings for Pistons and Cylinder Heads, and replaces the Air Ministry Specification D.T.D. 58A.

Copies of these two Specifications may be obtained from the British Standards Institution, Publications Department, 28, Victoria Street, London, S.W.1, price 1s. 2d. each, post free.

SEAPLANE TAKE-OFF CHARACTERISTICS

A Graphical Method of Estimation

By A. O. MATTOCKS (Whitworth Prizeman)

THE example taken is the estimation of the take-off characteristics of a seaplane having an all-up weight of 40,000 lb.

Fig. 1 shows a typical total resistance curve (i.e., the sum of the water and air resistances) together with the estimated available thrust curve for such a machine.

The take-off speed, v_0 is estimated as 70 knots. The acceleration of the machine at any instant is $\frac{dv}{dt}$ and therefore we get

$$T = \frac{M}{g}\frac{dv}{dt} \quad \ldots \quad (1)$$

where M is the all-up weight of the machine,
T is the excess thrust at any instant,
g is the acceleration due to gravity.

Equation (1) may be rewritten

$$dt = \frac{M}{g}\frac{dv}{T}$$

Therefore the time to take-off is $\frac{M}{g}\int_0^{v_0}\frac{dv}{T}$

The method herein described affords a means of obtaining the value of the integral $\int_0^{v_0}\frac{dv}{T}$ graphically

In Fig. 1 the excess thrust-speed curve has been obtained by subtracting the ordinates of the resistance curve from the ordinates of the thrust curve. The equation to this curve is $T = f(v)$ and the reciprocal curve will give values of $1/T$ for values of v. There is, however, no necessity to plot the reciprocal curve as the integral curve of the reciprocal curve can be drawn immediately as follows :—

Divide the excess thrust-speed curve into sections by erecting ordinates, taking care to choose the divisions to allow for any large changes of slope in the curve. Through the midpoints of the divisions on the curve draw lines, such as AB (Fig. 1), parallel to the horizontal axis. Join B to C, C being a point fixed at a distance 1in. from O and called the pole. At right angles to BC draw MP passing through O and intersecting the first ordinate produced in P. PM is drawn at right angles to the line corresponding to BC for the second sub-division, and the process is repeated until the complete integral curve of the reciprocal curve is obtained. Then the length RS is proportional to the take-off time. The scale of the integral, corresponding to the scales to which the curves in Fig. 1 are plotted is

$$1\text{in.} = \frac{5 \times 1.69}{1 \times 2{,}000}\ \text{f.p.s/lb.}\ [1\ \text{knot} = 1.69\ \text{f.p.s.}]$$

$$\text{Now take-off time} = \frac{M}{g}\int_0^{v_0}\frac{dv}{T}$$

And length RS = 5.75 inches.

$$\therefore \text{Time} = \frac{40{,}000}{32.2} \times \frac{5 \times 1.69}{1 \times 2{,}000} \times 5.75$$
$$= 30.2\ \text{seconds.}$$

To obtain the run to take-off it will be noticed that the integral curve of the reciprocal curve is also the velocity-time curve. Therefore, the area enclosed by ORF, stated in the correct units, gives the run to take-off.

This area, which may be found by a number of simple methods, is equal to 41.71 sq. in.

$$\therefore \text{Run to take-off} = \frac{40{,}000}{32.2} \times \frac{1.69}{400} \times 5 \times 1.69 \times \frac{41.71}{3}\ \text{yards}$$
$$= 618\ \text{yards.}$$

By way of comparison it is of interest to note that the results obtained for the above example by the normal method of straight estimation were :—

Time to take-off, 30.7 seconds.
Run to take-off, 625 yards.

APPENDIX

To determine the scales of the reciprocal curve and the integral curve.

Fig. 2 shows the reciprocal curve and the integral curve of the reciprocal constructed from the given curve $y = f(x)$. Let the scales be as marked : to determine $n[c]$ in terms of $k[A]$, $m[B]$ and d.

From the figure AF = BO and EF = DO
By similar triangles BO : CO : : CO : DO

$$\text{i.e., } BO \,.\, DO = (CO)^2 \quad \ldots \quad (2)$$

$$\text{i.e., } DO = \frac{1}{BO}(CO)^2 = \frac{1}{BO} \times \text{constant.}$$

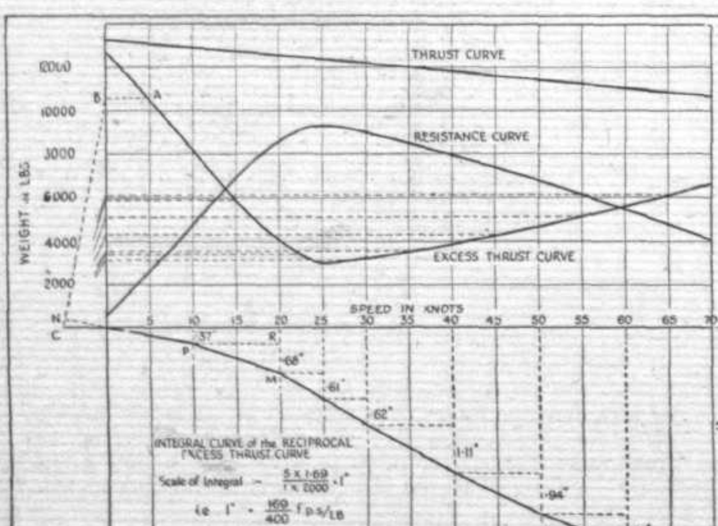


FIG.1. ESTIMATED TAKE-OFF CHARACTERISTICS FOR FLYING BOAT - ALL UP WEIGHT 40,000 LBS

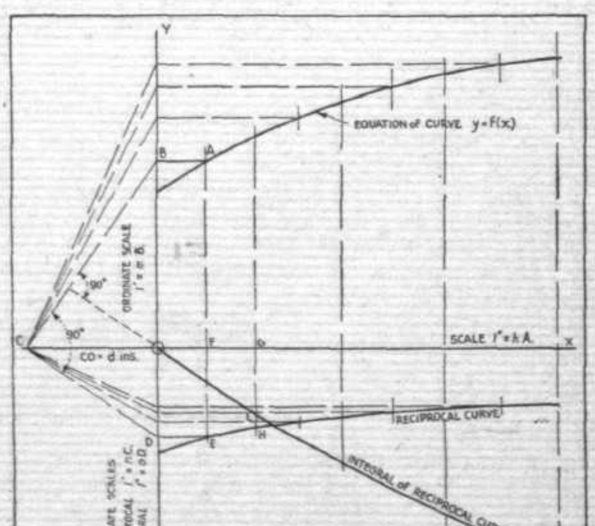


FIG.2

Because the ordinates of the reciprocal curve are to represent values of $1/y$, then

$$DO''n[C] = \frac{1}{BO''m[B]} \therefore n[C] = \frac{1}{BO.''\,DO''m[B]}$$

Substituting from (2)

$$n[C] = \frac{1}{(CO'')^2 m[B]}$$

$$\text{i.e. } n[C] = \frac{1}{d^2 m[B]}$$

For the integral curve we have

$$GL = FE \times OG$$

$$\therefore \frac{GL}{FE \times OG} = 1$$

From the figure

$$GL = GL \text{ inches} \times O[D]$$
$$FE = FE \text{ inches} \times n[C]$$
$$OG = OG \text{ inches} \times h[A]$$

$$\therefore \frac{GL}{FE \times OG} \text{(all in inches)} \times \frac{O[D]}{n[C] \times h[A]} = 1$$

$$\therefore \quad O[D] = n[C] \times h[A] \times \frac{OD \times OG}{GL}$$

By similar triangles

$$\frac{CO}{OD} = \frac{OG}{GL} \therefore CO = d = \frac{OG \times OD}{GL}$$

Hence $\underline{O[D] = n[C] \times h[A] \times d.}$

And $n[C] = \dfrac{1}{d^2 m[B]}$

$$\therefore \text{Integral scale} = \frac{1}{d^2 m[B]} \times h[A] \times d.$$

$$= \frac{h[A]}{d \times m[B]}$$

In the particular example given $h[A] = (5 \times 1.69)$ f.p.s.
$m[B] = 2{,}000$ lb.
and $d = 1''$

Therefore the scale of the integral curve of the reciprocal is

$$\frac{5 \times 1.69}{1 \times 2{,}000} = \frac{1.69}{400} \text{ f.p.s/lb.}$$

Clearly then, when estimating the run to take-off the scale of the area ORF (Fig. 1) is

$$1 \text{ sq. in.} = \frac{M}{g} \times \frac{h[A]}{d \times m[B]} \times h[A].$$

$$\text{i.e. } 1 \text{ sq. in.} = \frac{40{,}000}{32.2} \times \frac{5 \times 1.69}{1 \times 2{,}000} \times \frac{5 \times 1.69}{3} \text{ yards.}$$

In conclusion, I thank Short Bros. (Rochester and Bedford), Ltd., for permission to publish this article.

FLOAT AND HULL DESIGN

EXCEPT for the relatively few who have chanced to work for the three or four aircraft firms which specialise on marine aircraft, the general knowledge among draughtsmen, designers and engineers of the fundamental principles involved in this type of aircraft is probably limited. In view of the ever-growing importance of the flying boat in its applications to Empire air traffic, it is legitimate to assume that the interest in flying boat design will spread, and that gradually more and more will wish to familiarise themselves with the particular problems encountered. Hitherto it has not been too easy for a beginner in the subject to make a start. In his search through existing literature he has probably become discouraged by finding that on the one hand there is a wealth of text-books on naval architecture, which seems to have little enough connection with marine aircraft problems, while on the other there are many technical papers, lectures and books which deal with marine aircraft design, but which take for granted a knowledge of the fundamental problems.

Mr. Marcus Langley, M.I.Ae.E., A.M.Inst.N.A., who is an instructor in design at the de Havilland Aeronautical Technical School at Hatfield, during the last year or two planned a course of lectures on float design, intended for the students of the school. As the lectures proceeded, the scope of the subject grew, and Mr. Langley then conceived the idea of forming the lectures into a book. This he has now done, and the book, "Seaplane Float and Hull Design," published by Pitmans at 7s. 6d. net, is sure of a wide appeal among those who realise that the time may, and in all probability will come when a knowledge of marine aircraft is an asset.

One very great advantage of Mr. Langley's treatment of his subject is that he has assumed that the student knows nothing of the principles involved, other than a very superficial knowledge of the mechanics of fluids such as is taught in elementary mechanics. From a simple statement of basic principles, the student is taken through the application of these principles to such subjects as tank testing float and hull design, to design data.

A subject which tends to discourage many beginners is that of "sinkage" and change of trim when one compartment is flooded. The chapter which deals with this is admirably clear, a simple rectangular "box" being taken first as the simplest example, and an actual flying boat hull afterwards. This is a useful addition not generally found in textbooks.

The increasing speed of modern flying boats has brought to light the existence of a second "hump" just below the take-off speed. In the more lightly loaded flying boats of a few years ago this second hump would not have appeared, as the wing loading would have been so low that the wing would have lifted the boat out of the water first. This subject is well treated in the book, and, incidentally, indicates why, with wing loadings increasing as they tend to do, variable-pitch airscrews may become necessary.

As an introduction to the more advanced study of the subject, Mr. Langley's book is admirable and can be thoroughly recommended.

TECHNICAL LITERATURE

SUMMARIES OF AERONAUTICAL RESEARCH COMMITTEE REPORTS

REPORTS published by His Majesty's Stationery Office, London, which may be purchased directly from H.M. Stationery Office at the following addresses: Adastral House, Kingsway, W.C.2; 120, George Street, Edinburgh; York Street, Manchester 1; St. Andrew's Crescent, Cardiff; 15, Donegall Square West, Belfast; or through any ordinary bookseller.

ON THE ANALYSIS OF EXPERIMENTAL OBSERVATIONS IN PROBLEMS OF ELASTIC STABILITY. By R. V. Southwell, F.R.S. R. & M. No. 1610. (1 page.) December, 1931. Price 2d. net.

Abstract of paper published in Proceedings of the Royal Society, A. Vol. 135 1932.

Printed and Published by His Majesty's Stationery Office, London.

To be purchased directly from H.M. Stationery Office at the following addresses:—Adastral House, Kingsway, London, W.C.2; 120, George Street, Edinburgh, 2; York Street, Manchester, 1; 1, St. Andrew's Crescent, Cardiff; 80, Chichester Street, Belfast, or through any Bookseller.

THE FLOW INDUCED BY A JET OF AIR. By H. C. H. Townend, D.Sc. R. & M. No. 1634. (3 pages and 3 diagrams.) June 20, 1934. Price 6d. net.

The character of the motion set up at the boundary of a jet as it discharges into a mass of air has been studied by taking cinematograph records of the flow pattern. These show that the character of the eddies which form at the boundary of the jet in consequence of the fluid friction there depends upon the external form of the orifice producing the jet. Two clearly defined regimes have been observed and are here described.

AIRCRAFT VIBRATION. By Hayne Constant, M.A., A.F.R.Ae.S. Communicated by the Director of Scientific Research, Air Ministry. R. & M. No. 1637. (30 pages and 23 diagrams.) October, 1934. Price 2s. 6d. net.

The systematic study of aircraft vibration has only been in progress for a short time. As there is little earlier work on the subject the investigation was commenced *ab initio* and this necessitated considerable time being spent in clearing the ground and developing suitable instruments. The present report describes mainly those sections of the work upon which some finality has been reached. In some instances, however, the conclusions arrived at must be regarded as liable to modification when fuller information becomes available.

In the majority of tests the instrument used to record vibration was a vibrograph constructed by the Cambridge Scientific Instrument Company and modified in some particulars to meet the specific requirements of the work described in this report. This vibrograph has been used to measure the vibration set up in the mountings of engines running on the test bed and on the hangar, and in the fuselages of aircraft on the ground and in flight. In the flight tests it has frequently only been possible to measure the vibration at a single point of the fuselage. From ground tests, however, an indication of the manner in which the vibration varies along the fuselage has been obtained.

An aircraft when vibrating, forms a complicated elastic structure having inertia and is subjected to an involved system of forcing impulses and, in the existing state of knowledge, it is difficult to predict vibration characteristics except in general terms.

Forcing impulses in general cause greater vibration the lower the frequency. Vibrations of low frequency are the most noticed by personnel and are usually the cause of "roughness."

The chief sources of aircraft vibrations are :—

(i) The half order harmonic of the engine torque reaction, usually due to faulty ignition or distribution.

(ii) Inaccuracies in airscrew manufacture, more particularly airscrew out of track.

(iii) With two-bladed airscrews, second order airscrew aerodynamic couples caused by the airscrew axis being inclined to the relative wind.

(iv) With two-bladed airscrews, second order airscrew vibration caused by periodic gyroscopic couples when turning.

Of these four sources of vibration the first can be reduced by supercharging and improved carburation ; the second by improved methods of airscrew manufacture ; the third and fourth only by the fitting of an airscrew having more than two blades. As a rule, engine unbalance is not an important source of vibration.

It is considered that most instances of serious vibration can be cured, but such reduction in vibration may sometimes involve a loss of aircraft performance greater than is justified by the increased comfort of the machine.

MEASUREMENTS OF WATER PRESSURE ON THE HULL OF A BOAT SEAPLANE. By E. T. Jones, M.Eng., and W. H. Davies. Communicated by the Director of Scientific Research, Air Ministry. R. & M. No. 1638. (46 pages and 56 diagrams.) March, 1934. Price 3s. 6d. net.

The first measurements of water pressure on a flying boat hull were made at the Isle of Grain in the years 1919 and 1920. These experiments are described in R. & M.683.[1] Similar experiments were made on a different shape of hull in 1924 and are described in R. & M.926.[2] In these experiments only the pressure that was exceeded at different stations was indicated, there being no record on a time basis. Similar apparatus to that used in the above tests, but with four plungers in each unit instead of a single plunger, and recording on a time basis, was developed in America more recently for measuring the pressure on hulls and floats. The American tests are described in three reports, N.A.C.A. reports Nos. 290[3], 328[4] and 346[5].

The wing loading of seaplanes has been considerably increased and the general design of hulls and floats has changed since the previous British tests were made. It was desired therefore to make further tests on representative hulls of different families of modern boat seaplanes.

The pressure over the hull bottom of a Southampton boat seaplane has been recorded at 23 stations during a series of normal landings and take-offs at different weights and during abnormal landings at one weight. The pressure has also been recorded during take-off and landing in a 3½ ft. sea.

During two of the abnormal landings where the rate of descent at impact was high the pressure distribution and the normal force on the hull has been deduced.

The intensity of pressure during a normal landing made in calm water is higher than during the take-off. The area over which the pressure extends is from the front step to a point along the keel about a beam length forward of the front step. The mean pressure intensity over this area irrespective of time is about 7 lb./sq. inch at the normal load (15,300 lb.) and varies approximately as $W^{1 \cdot 7}$, while the mean simultaneous pressure is only about 4 lb. per sq. inch.

Local pressures of 30 lb. per sq. inch approximately were recorded twice and very high pressures are not registered over a large area simultaneously. The pressure aft of the front step is negligible in normal landings and the highest pressure reached in an abnormal landing was 7 lb./sq. inch at the rear step.

High pressures are distributed over a larger area during normal landings and take-offs in a rough sea than during abnormal landings made in a calm sea, and it is possible that normal tests made in a 4 ft. sea accompanied by a swell, would give pressures exceeding those during abnormal tests made in a calm sea.

[1] R. & M.683. Experiments with full-sized machines. Second Series. Baker and Keary.
[2] R. & M.926. P.S. Flying Boat N.86 Impact Tests. Experiments with full-sized machines. Third Series. The William Froude National Tank.
[3] N.A.C.A.290. Water pressure distribution on seaplane float. Thompson.
[4] N.A.C.A.328. Water pressure distribution on a twin float seaplane. Thompson.
[5] N.A.C.A.346. Water pressure distribution on a flying boat hull. Thompson.

EFFECT OF WIND TUNNEL WALL INTERFERENCE ON THE PITCHING MOMENTS OF LARGE MODELS IN THE DUPLEX TUNNEL. By W. L. Cowley, A.R.C.Sc., D.I.C., and G. A. McMillan, M. Eng., of the Aerodynamics Dept., N.P.L. R. & M. No. 1639. (13 pages and 4 diagrams.) November 5, 1934. Price 9d. net.

This investigation is concerned with the tunnel correction for pitching moment on a model aircraft which is large compared with the size of the tunnel. Attention is devoted to a Duplex Tunnel in which the breadth is twice the height. It is possible to extend the work to other tunnels, but unfortunately very little of the numerical work can be used in the extension.

Glauert's* formula only applies when the model is small compared with the tunnel. In the case of a model of span 11 ft. 6 in. in a 7 ft. × 14 ft. tunnel the correction constant in Glauert's formula was 0.386 whereas the present investigation showed it should be 0.212 or 0.164 according as the wing loading was elliptical or uniform.

* "The Elements of Aerofoil and Airscrew Theory," H. Glauert, M.A., pp. 126–198.

THE AILERON POWER OF A MONOPLANE. By A. G. Pugsley, M.Sc., and H. Roxbee Cox, Ph.D., D.I.C., B.Sc. Communicated by the Director of Scientific Research, Air Ministry. R. & M. No. 1640. (15 pages and 10 diagrams.) April, 1934. Price 1s. net.

Two recent lines of investigation have drawn attention to the need for a detailed consideration of aileron effectiveness. In the first place work on reversal of aileron control due to wing twisting* has indicated the importance of wing elasticity in lateral control problems and has pointed to the need for guidance in deciding upon the minimum amount by which the reversal speed for an aeroplane should exceed the maximum speed at which it may fly. Secondly, the trend of recent manoeuvrability investigations has emphasised the desirability of establishing quantitative criteria representative of various aspects of manoeuvrability ; one of these criteria should presumably relate to aileron effectiveness.

The present report describes some theoretical work suggested by the above considerations on the aileron effectiveness of monoplanes. For this work the first step was to decide upon a measure of aileron effectiveness having, if possible, a simple physical significance of direct practical interest. Before deciding upon this measure the motion resulting from a sudden aileron displacement was reviewed.

It is found that when allowance is made for wing twisting the aileron power of a given monoplane reaches its maximum value when the speed is about 58 per cent. of the reversal speed for its wings. At a given speed and for a given aileron area the aileron power is theoretically greatest when the monoplane wings are tapered in plan form and each aileron has a span in the region of 0.7 of the monoplane semi-span. Considerations of aerodynamic efficiency and control operating force complicate the problem of deciding upon the best aileron span in practice.

* "Theory of loss of lateral control due to wing twisting." H. Roxbee Cox, Ph.D., and A. G. Pugsley, M.Sc. (R. & M. 1506).

THE REACTION ON A WING WHOSE ANGLE OF INCIDENCE IS CHANGING RAPIDLY. WIND TUNNEL EXPERIMENTS WITH A SHORT PERIOD RECORDING BALANCE. By W. S. Farren, M.B.E. R. & M. No. 1648. (24 pages and 37 diagrams.) January 15, 1935. Price 2s. 3d. net.

The work described in this report was undertaken in order to investigate more fully certain observations made in previous researches in this Laboratory on the characteristics of wings at or near the stall. In the first place it was established in the work described in R. & M. 1561[1] that when a wing is started suddenly in motion at an angle of incidence well above that at which the stall occurs in steady motion the flow remains unstalled during the first few chords travel of the wing. This suggested that the lift of a wing whose angle of incidence is rising fairly rapidly, from a value below the normal stalling angle to one well above it, may considerably exceed that measured at fixed angles of incidence above the stall.

In the second place the experimental study of stalling described in R. & M. 1588[2] made it clear that over a certain range of angle of incidence above the stall large fluctuations with a relatively long mean period occur in the forces on a wing and in the associated flow round it. The existence of similar fluctuations on the full scale has been confirmed by experiments in flight, which were briefly described by Professor Jones in the Wilbur Wright lecture, 1934,[3] and will form the subject of a later report. Moreover they were found to be associated with a type of behaviour of the aeroplane which is undesirable and may be dangerous.

The results can be briefly summarised as follow :—

Class I.—(Angle of incidence increasing or decreasing).—A large "hysteresis"* effect exists above the stall for all the types of wing tested. The force-angle curve is a function of both the rate of change of angle, and of the sense of the change, i.e., whether increasing or decreasing. The magnitude of the effect depends to some extent on the shape of the wing profile.

The full scale inferences to be drawn from these results must remain for the present largely a matter for speculation. The Reynolds number of the experiments was low (about 1.2×10^5). The condition of the wings was nominally two-dimensional, so that the effect of a finite span is not represented. On the other hand, the effect of the tunnel boundary layer and of end leaks, though probably of small magnitude, makes it impossible to regard the numerical results as more than an approximation to the two-dimensional values. Further the tunnel is small in relation to the wing, and the blocking effect of the stalled wing is appreciable and its precise interpretation in terms of "free air" condition is uncertain. Nevertheless there does not seem to be any reason to believe that the general nature of the phenomenon described can be largely influenced by any of the considerations mentioned, though its extent may, of course, depend appreciably on Reynolds number.

If the "peak" at increasing angles of incidence exists on the full scale, and if its magnitude is of the order mentioned above, its effect in a landing carried out as recorded in R. & M. 1406, "Take-off and Landing of Aircraft."—D. Rolinson, would be appreciable. Rates of rotation considerably greater than 1 deg. in 2.5 chords were recorded in those experiments. A 30 per cent. excess of lift over weight enduring while the aeroplane travels 5 chords, or about ¼ sec. at stalling speed, would produce an upward velocity of 5 ft. per sec., sufficient to delay the final drop on to the ground very noticeably.

It is not suggested that these figures can be applied with any great confidence in this way. But the effects described are of the right order of magnitude to serve as a basis for explaining both these full scale observations and others of a less precise nature but none the less well authenticated, such as the "ground effect."

[1] "The flow near a wing which starts suddenly from rest and then stalls." Aeronautics Laboratory, Cambridge.
[2] "An experimental study of the stalling of wings," Aeronautics Laboratory, Cambridge.
[3] Wilbur Wright Lecture, *Journal of the Royal Aeronautical Society*, September, 1934.
* The term "hysteresis" may be considered hardly appropriate, but it has been widely used to denote that a function of some variable goes through a series of values when the variable is increasing which are different from those through which it passes when the variable is decreasing without any essential implication as to the relation between the two series of values and the underlying mechanism.